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CAPACITY OF DUAL LEFT-TURN LANES

State of the Art

Final Report

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16. ABSTRACT Based on available literature, the applications, quidelines for use, and capacity of dual left-turn lanes were reviewed. This review revealed that there is variation in the application and use of dual left-turn lanes. Most applications involve exclusive turn lanes and protected signal phases; however, other operational configurations and traffic control may be found.

Research studies related to dual left-turn lanes have generally dealt with questions related to capacity, and the findings indicate considerable variation. A recent study found that dual left-turn saturation flow rates at sites in a larger city approach through movement values. That study also found variations in the results from different cities.

A commonly quoted current practice guideline suggests that a left-turn volume of 300 vehicles per hour or more merits consideration of a dual left-turn lane. The 1985 Highway Capacity Manual documents the analysis of standard intersections with exclusive dual left-turn lanes and protected signal phases. Work by Leisch and the Canadian Capacity Guide for Signalized Intersections contain information on the analysis of other geometric and operational conditions.

Recommendations for further research are included in the report.

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METRIC CONVERSION FACTORS

The material contained in this report is presented in terms of English units. The following factors may be used to convert the measures used in this report to the International System of Units (SI):

1 foot = 0.3048 meter

1 meter = 3.2808 feet

1 mile per hour (mph) = 1.6093 kilometers per hour (kph)

1 kph = 0.6214 mph

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INTRODUCTION

In 1985, a new edition[8] of the Highway Capacity Manual was published by the Transportation Research Board as Special Report 209. When published, it was considered to reflect the best available collection of techniques for estimating highway capacity; thus it was intended to replace previous documents and references that have been used. It was recognized, however, that the publication was "a milestone in the growing body of knowledge of highway capacity - not a conclusion". As additional research is completed and further knowledge is gained, it was anticipated that the Manual would be appropriately revised. Even at the time of publication, a major research effort, sponsored by the National Cooperative Highway Research Program, was underway. That research should provide the basis for revising and updating the material related to multilane highway capacity. Since that time, other highway capacity oriented research has been initiated by a number of organizations.

The 1985 Highway Capacity Manual[8] is the third edition of a series of manuals that have been published in the United States. The first formal manual[6] was published in 1950 by the Bureau of Public Roads, U. S. Department of Commerce. In 1965, a revised edition[7] of the Highway Capacity Manual was published by the Highway Research Board as Special Report 87. In all cases, these publications are the result of the efforts of a number of individuals and organizations even though the primary responsibility has been with the Highway Research Board Committee on Highway Capacity and subsequently the Transportation Research Board Committee on Highway Capacity and Quality of Service. Certainly, these manuals are not the only source of information on highway capacity. The literature contains a number of papers and publications on the subject. In some cases, that information has been incorporated into subsequent editions of the Highway Capacity Manual. Also, similar manuals have been developed by some other countries.

THE PROBLEM AREA

While there are a number of areas where additional highway capacity research is needed, one specific topic that deserves further work is the capacity of the dual or double left-turn lanes at signalized intersections. The 1985 Highway Capacity Manual[8] does contain a factor for use in the calculation of the capacity of the dual left-turn lane; however that factor is based on very limited research. Also, previous work has shown that there can be considerable variation in the capacity of these lanes depending on the behavior of motorists and the intersection environment.

This topic is particularly pertinent in Arizona because of the increasing use of dual left-turn lanes at intersections. The increased use of these lanes probably is the result of the continued increase in size of the metropolitan areas in the State and the corresponding increase in traffic demands on the street and highway systems in those areas. In addition, the street network in the metropolitan areas has generally developed on the one mile grid of major arterials. With this type of street network, the opportunity for accommodating turn movements is quite restricted.

Many cities have minor arterials located approximately at the half mile intervals between the major arterials; however the street patterns in the metropolitan areas of Arizona do not always have the intermediate minor arterials. The lack of the minor arterials increases the demand for turn movements at the intersections of the major arterial streets. As turn movement volumes increase, one design alternative is to utilize a dual rather than a single turn lane.

At the current time, there are several different types of applications of dual left-turn lanes in Arizona. Generally, the dual turn lanes are used in conjunction with a protected traffic signal phase. In some cases, however, there are applications with permitted plus protected phases. Also, there is a limited number of intersections where one of the dual left-turn lanes is shared with a through or right-turn movement. The latter two situations are not addressed by the methodologies in the <u>Highway Capacity Manual</u>(8).

<u>STUDY SCOPE AND PURPOSE</u>

The objective of this study is to prepare a state-of-the-art report identifying current practices in the determination of dual left-turn lane capacity, operational needs, and standards for their installation. Also, a part of the objective is the development of a research work plan for any recommended research.

More specifically, the following tasks were included in the project:

1. Review all available research studies on the determination of the capacity and application of dual left-turn lanes.

2. Review, evaluate, and summarize the current practices in the determination of dual left-turn capacity, operational needs, and any standards used for their installation.

3. Identify and review any studies on what effect the dual left-turn lanes have on total intersection capacity, and the installation of dual left-turn lanes on traffic signal cycle length.

4. Provide recommendations on the scope and extent of further studies.

5. Develop a detailed work plan for any recommended research and establish the anticipated project duration and estimated budget.

6. Prepare a state-of-the-art report summarizing the results of tasks 1 through 5.

LIMITATIONS IN SCOPE

It was not the intent of this study to review all aspects of intersection capacity or even left-turn operations and capacity. The work in this study was specifically limited to the area of dual left-turns. In some cases, the report contains references to other aspects of intersection capacity; however these references have been included only because of the pertinence to dual left-turn conditions.

DUAL LEFT-TURN LANE APPLICATIONS AND GUIDELINES

The literature contains only a limited number of papers or reports that specifically address dual left-turns. Generally, the literature on the subject is restricted to the period from the early 1960's to the present.

While the early studies and discussions tended to deal with questions, a Committee of the Institute of Traffic Engineers (ITE), now the Institute of Transportation Engineers, published a state-of-the-art report[22] in 1975 on the usage and effectiveness of double left-turn movements. The work of the Committee included the identification of commonly used configurations, a discussion of design factors, a review of policies and warrants, the application of traffic control devices, a review of accident experience, and capacity factors.

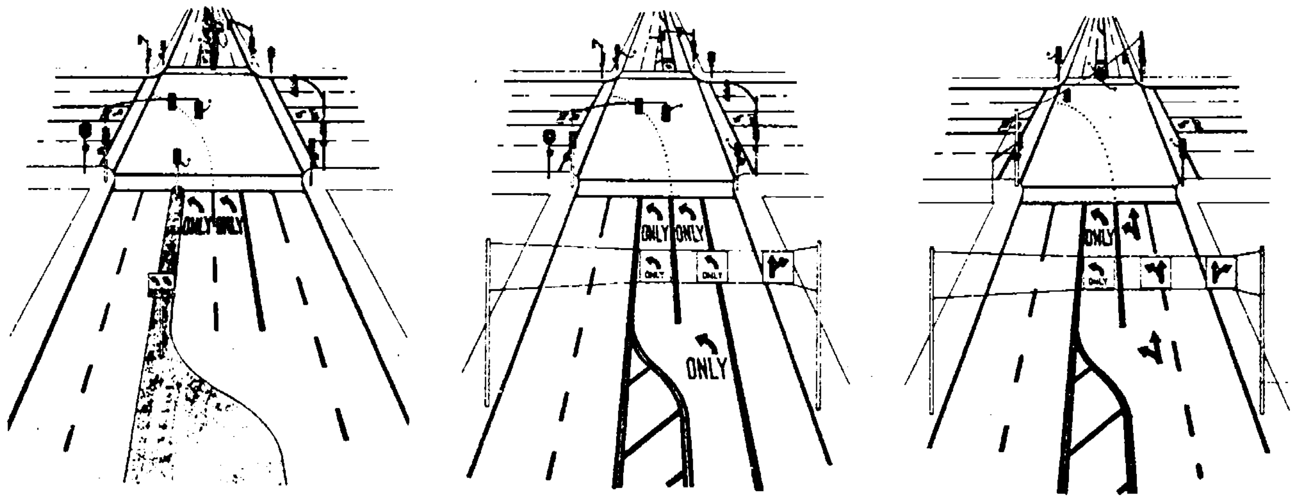
The common configurations as reported by the ITE Committee are shown in Figure 1. These configurations all use exclusive left-turn signalization.

With respect to design factors, the Committee noted the importance of providing adequate turning roadways for the left-turning vehicles. Lane widths, the width of the roadway accepting the double turn, the angle of the turn, and the adequacy of signs and markings were all cited as factors that could influence the efficiency and capacity of the double left-turn lanes. In addition, concern was expressed about alignment of other traffic lanes if it is necessary to shift those lanes for the installation of double left-turn lanes. Other areas of concern were left-turn storage requirements, vehicular movements through the area of influence of the double left-turn (including upstream and downstream conditions such as high volume driveways and weaving needs), and signing capabilities.

The Committee reported that few jurisdictions had actually adopted a numerically based policy or warrant. The California Department of Transportation was cited as having a warrant based on a peak hour left-turn volume of 300 vehicles per hour. Other reported reasons for installing double left-turn lanes included:

- intersection capacity,
- available left-turn storage lengths,
- reduction of delay at the intersection, and
- observations which indicate that traffic operations would be enhanced.

One of the areas reviewed by the ITE Committee dealt with traffic control devices and signalization. Most of the



*Exclusive double left-turn lane (both lanes shadowed; * left-turn signal).*

*Exclusive double left-turn lane (one trap lane; *left-turn signal).*

*Permissive double left-turn lane (one lane optional; *left-turn signal).*

FIGURE 1

LEFT-TURN LANE CONFIGURATIONS[22]

reported intersections with double left-turn lanes had traffic signal control; however a very limited number of locations had stop signs, yield signs, or no traffic control devices. At the signalized intersections, the majority of the installations used a protected turn phase.

While the Committee attempted to investigate accident experience, conclusive information was not obtained. Some jurisdictions did respond that the use of double left-turn lanes had reduced collisions, and others reported no significant affect. This report by the ITE Committee was the only reference that was found which addressed the accident or safety element.

In terms of capacity, the Committee referenced the work of Ray[17] and Leisch[12]. The discussion of these references is included in a later section of this report that specifically addresses the capacity of the dual left-turn lanes.

The published American Association of State Highway and Transportation Officials (AASHTO) policy[2,3] on dual left-turn lanes has not changed in a number of years. In fact, the policy statement published in 1984[3] is the same as that published in 1973[2]. The AASHTO policy is as follows:

> "Where turning traffic is too heavy for a single lane and the crossroad or street is wide enough to receive the traffic, two turning lanes should be provided. Pavement marking, contrasting pavements, and signs should be used to discourage the through driver from inadvertently entering the median lanes. Barrier-type separators should not be used because of the potential hazard if they are accidentally struck.
>
> Left turning vehicles leave the through pavement to enter the median lanes in single file, but once within it, store in two lanes and, on receiving the green indication, turn simultaneously from both lanes. With three-phase traffic signal control, such an arrangement results in an increase in capacity of approximately 180 percent of that of a single median lane. Occasionally, there are operational problems as a result of the two-abreast turns, especially the problems of sideswipe accidents. These usually result from too sharp a turning radius or a roadway that is too narrow. The receiving leg of the intersection must have adequate width to accommodate two lanes of turning traffic. A width of 30 ft. is used by several highway agencies."

Neuman[14] included a discussion of the guidelines for use and design of double left-turn lanes in the more recently published Intersection Channelization Design Guide. The guidelines for use are basically volume oriented. It is noted that double left-turn lanes should be considered at any signalized intersection with high left-turn design hour demand volumes, and a general "rule-of-thumb" of 300 vehicles per hour or more is cited as the appropriate demand volume for consideration of the double left-turn lanes. In addition, the following design guidelines are given by Neuman:

- The throat width for the turning traffic is the most important design element. Drivers are most comfortable with extra space between the turning queues of traffic. Because of the offtracking characteristics of vehicles and the relative difficulty for acceptance of two-abreast turns, a 36 ft. throat width is desirable for acceptance of two lanes of turning traffic. In constrained situations, 30 ft. throat widths are acceptable minimums.

- Guiding pavement markings to separate the turning lanes are recommended. The Manual of Uniform Traffic Control Devices (MUTCD) recommends 2 ft. long dashed lines with 4 ft. gaps to channelize turning traffic. These channelization lines should be carefully laid out to reflect offtracking and driving characteristics.

- Designers should carefully sign and mark double turning lanes to prevent inadvertent "trapping" of through traffic. Fully shadowed lanes should be designed wherever possible. Up to a full lane width of recovery area should be provided in the median opposite the double turning lane for recovery of trapped vehicles.

- Designers should check for possible conflicts involving left-turns opposing double left-turns. Where such simultaneous movements occur, special pavement marking to separate opposing turns may be necessary.

The discussion in Section 2B-18 of the MUTCD[15] suggests that the use of double left-turn lanes is a function of capacity. It also suggests that protected signal phases should be used for the turn movements. The following paragraph is an excerpt from the Manual:

"Lane-Use Controls permitting left (or right) turns from two (or more) lanes are normally warranted whenever the turning volume exceeds the capacity of one turning lane, and when all movements can be accommodated in the lanes available to them. When multiple-lane left turns are to be permitted at signalized intersections, special signal phasing should be used to allow the turning movements without interference from opposing or cross traffic."

The previous edition of the Manual[14] contained a similar statement.

In a recently published article, Agent[1] presented guidelines for the use of protected/permissive left-turn phasing. Based on studies of signalized intersections in Kentucky, the results indicate that the protected/permissive left-turn phasing is preferable because of the savings in time. The study found that the protected/permissive phasing resulted in an increased accident potential. The recommended guidelines specifically state that the protected/permissive phasing should not be used when there are double left-turn lanes on an approach. It is important to note, however, that the data base used in the study did not include any intersections with dual left-turn lanes. The recommended guideline for dual left-turn lanes is not actually based on the field data from the study.

A spot check of several highway and traffic organizations in Arizona was made in an effort to determine any formal policies regarding the use and/or design of dual left-turn lanes. While none of the organizations had formal policies, most had some type of informal and unwritten guidelines that were followed.

DUAL LEFT-TURN CAPACITY

The discussion of dual-left turn capacity which follows is divided into two sections. In the first section, pertinent research studies of dual left-turn capacity are reviewed. The latter section presents a summary of the evolution of dual left-turn capacity methodologies as well as the current approach to capacity calculations.

RESEARCH STUDIES

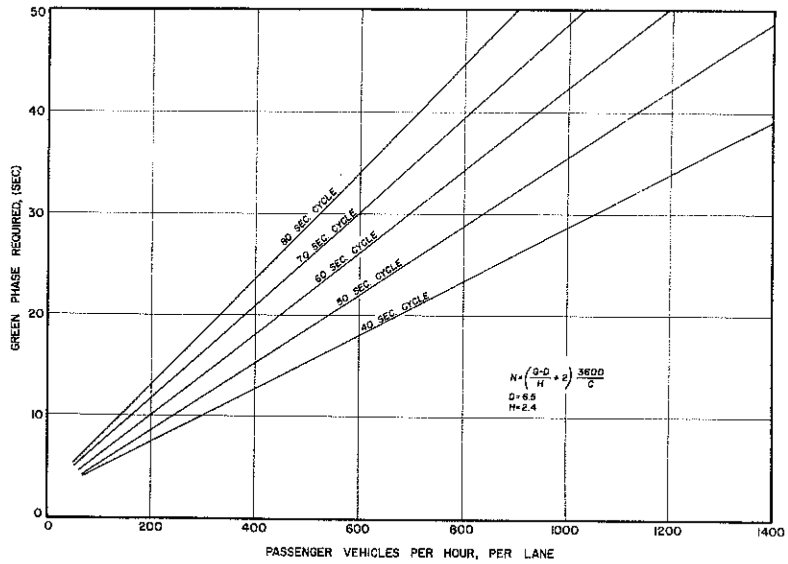
One of the early documented studies of dual left-turn capacity was undertaken by Capelle and Pinnell[5] in their research related to the capacity of signalized diamond interchanges. Traffic movements were studied at two diamond interchanges in the Houston area, and data were obtained for the start delay and the average time-headway for each type of movement at the signalized intersections. The following summarizes the findings:

Movement Type	Starting Delay (sec.)	Ave. Time-Headway (sec.)
Through	5.8	2.1
Single left-turn	5.8	2.1
Single right-turn	5.8	2.1
Dual left-turns		
Inside lane	6.5	2.4
Outside lane	6.5	2.2

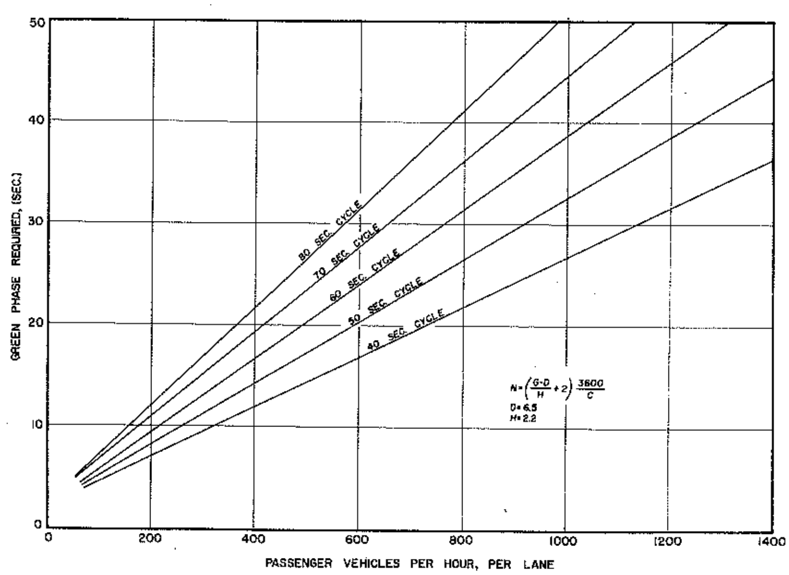
In this study, the inside lane was the left-turn lane on the median side of the roadway. Based on this information, Capelle and Pinnell concluded that the dual left-turn lanes have a reduced capacity compared to the single turn lane situation. The reduction in capacity was attributed to drivers staggering the position of the vehicles in making the turn movement. Design capacity charts were developed for the dual left-turn lanes as shown in Figure 2.

The current approach to signalized intersection capacity is to use saturation flow concepts. The saturation flow rate is defined as:

> "The equivalent hourly rate at which vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal was available at all times, and no lost times are experienced, in vehicles per hour of green, or vehicles per hour of green per lane."[6]



a) Inside Left-Turn Lane



b) Outside Left-Turn Lane

FIGURE 2

DESIGN CAPACITY BY CAPELLE AND PINNELL[5]

If the saturation flow rates are calculated based on the average time-headway found in the Houston study, the values are:

Movement Type	Calculated Saturation Flow Rate (vphg)
Through and single turn lanes	1714
Dual left-turn lanes	
Inside lane	1500
Outside lane	1636

These figures indicate that the inside left-turn lane has a flow rate that is 88 percent of the through value and the outside lane is 95 percent of the through rate.

In their book on traffic signals, Webster and Cobbe[24] included a discussion of the effect of the radius of a turning roadway on saturation flow. The effect of the radius for double lane traffic streams is given as:

$$s = [3000] / [1 + (5/r)]$$

where

s is the saturation flow in passenger car units per hour

r is the radius in feet

Because this equation applies to British conditions, it is for double right-turn lanes which are the equivalent of double left-turn lanes in the United States. Webster and Cobbe referenced this equation to work by Webster[23].

In 1965, Ray[17] reported on studies of dual left-turn lanes at signalized intersections in Sacramento County, California. Based on the field studies, it was found that:

- While there was some variation depending on the location, the average distribution of lane use was 51.3 percent for the inside lane and 48.7 percent used the outside lane.

- The average time-headway for the inside lane ranged from 2.6 to 2.9 seconds and from 2.8 to 3.5 seconds for the outside lane.

These headway figures indicate that the inside lane has a greater capacity potential which is in contrast to the findings of the earlier work by Capelle and Pinnell[5]. Ray concluded that "it would seem reasonable to expect at least a 75 percent increase in capacity by adding a second left-turn lane".

Assmus[4] undertook field studies at seven sites in the Chicago area in 1970. The intersection approaches that were studied included several different approach configurations of dual left-turn lanes which ranged from fully "shadowed" to those with "trap lanes". An analysis was carried out which compared the operation of the dual left-turn lanes with the 1965 Highway Capacity Manual[7]. The analysis revealed that the procedures in the Manual under-predicted the observed volumes at the study sites from 17 to 74 percent. Assmus also made note of the fact that drivers tended not to turn two-abreast, but completed the turn movement by "staggering" the position of the vehicles. At three sites where there was less than 1.5 percent commercial vehicles, the average time-headways and saturation flows were:

Lane	Average Time-Headway (sec.)	Saturation Flow (vphg)
Inside left-turn	2.34	1,540
Outside left-turn	2.32	1,550
Inside through	2.27	1,585
Outside through	2.25	1,600

While Assmus concluded that the capacity of the dual left-turn lanes was not very sensitive to normal range of cross street widths, it was noted that a major reduction in capacity would occur with a cross street width of less than 30 feet. In addition, it was found that capacity of the lanes was reduced approximately 1.8 percent for each percent of commercial vehicles. Finally, it was suggested that the capacity of dual left-turn lanes might be affected by:

- angle of turn
- turning radii
- medians on the approach
- medians on the cross street
- length of storage available
- striping and signing
- volume in the adjacent through lane

An article was published in 1978 which summarized a study by Kunzman[10]. In that work, through, left-turn, and dual left-turns were studied at 175 locations in Orange County, California. It was reported that through and single left-turn lanes had average capacities of 1700 vehicles per lane per hour of green while the dual left-turn lane had an average value of 1550.

The most recent reported research was accomplished by Stokes[18] in which dual left-turn lanes were studied at a total of 14 intersections in three different Texas cities. A summary of this work is also found in a paper by Stokes, Stover, and Messer[20]. Stokes objective was to develop reliable estimates of saturation flows for dual left-turn lanes. As part of that research, an effort was made to relate variations in flow to physical and operating characteristics of intersection approaches. The results of the field studies revealed that average saturation flow for dual left-turn lanes at the Austin and College Station locations was 1636 vphg. At the Houston sites, the average saturation flow was found to be 1800 vphg. Stokes concluded that the saturation flows for dual left-turn conditions were higher than previously thought and that the observed higher value at the Houston sites could be related to traffic conditions in a larger city. While the departure headways did vary depending on the city, little difference was found when the inside and outside lanes were compared for a given city. It is recommended that a saturation flow rate of 1600 vphg be used for most planning applications, and that rate is applicable for mixed traffic conditions where heavy vehicles make up 3 to 5 percent of the left-turn volume.

Stokes used correlation analysis to examine the effect of intersection and traffic characteristics on departure headways. The following factors were found to be significantly correlated at the 5 percent level with the inside lane departure headways:

1. Turn bay taper length;
2. Turn bay storage length;
3. Approach grade;
4. Percent heavy vehicles in the inside lane;
5. Headway compression factor for the inside lane;
6. Headway compression factor for the outside lane; and
7. Left-turn green time.

For the outside lane, the following list of factors was found to be significantly correlated:

1. Approach grade;
2. Width of inside lane;
3. Width of outside lane;
4. Combined width of inside and outside lanes;
5. Headway compression factor for the inside lane;
6. Headway compression factor for the outside lane; and
7. Left-turn green time.

For that study, the "headway compression factor" was defined as the compression, or shortening, of the left-turn departure headways as the demand per cycle increases relative to capacity. In other terms, this was defined as the compression of the departure headways as the queue length increases relative to the green time.

Stokes also examined left-turns from the dual turn lanes during the amber and red traffic signal indications. In addition to the original work by Stokes[18], a paper dealing with this topic was later published by Stokes, Messer, and Stover[19]. In this research, the number of left-turning vehicles that entered the intersection during the amber or red signal was determined. It was found that the average number of vehicles during the amber signal did not substantially differ between the two lanes; however drivers made fewer left-turns from the outside lane during the red signal. The authors suggest that about four vehicles can be expected to enter the intersections from the two lanes at the end of the green period.

Using the results from field studies conducted at a number of locations in the United States, Zegeer[25] analyzed intersection capacity factors. Zegeer examined the use of the dual left-turn lanes and determined that 50.3 percent of the left-turning vehicles used the inside lane. Reference is made to the lane distribution concepts presented in Transportation Research Circular 212[9] and the adjustment factor of 0.91 which results with 55 percent of traffic in the heavier lane of travel. Zegeer concludes that the overall adjustment factor for dual left-turns should be 0.94 rather than 0.92 as given in the 1985 Highway Capacity Manual[8].

EVOLUTION OF CAPACITY METHODOLOGIES

The 1965 Highway Capacity Manual[7] included a procedure for determining the capacity of dual left-turn lanes. At that time, signalized intersection capacity was determined for each of the intersection approaches. For an approach with separate turn lanes and separate signal control, the following maximum service volumes were utilized:

Level of Service	Service Volume (vphg)
A, B, & C	800
D	1,000
E	1,200

These service volumes were based on 5 percent trucks and a 10 ft. lane. If two or more turning lanes were provided, the additional lanes were to be assigned 80 percent of the service volume for one lane. Thus, a dual left-turn lane would have a service volume of 1.8 times the value for a single turn lane condition.

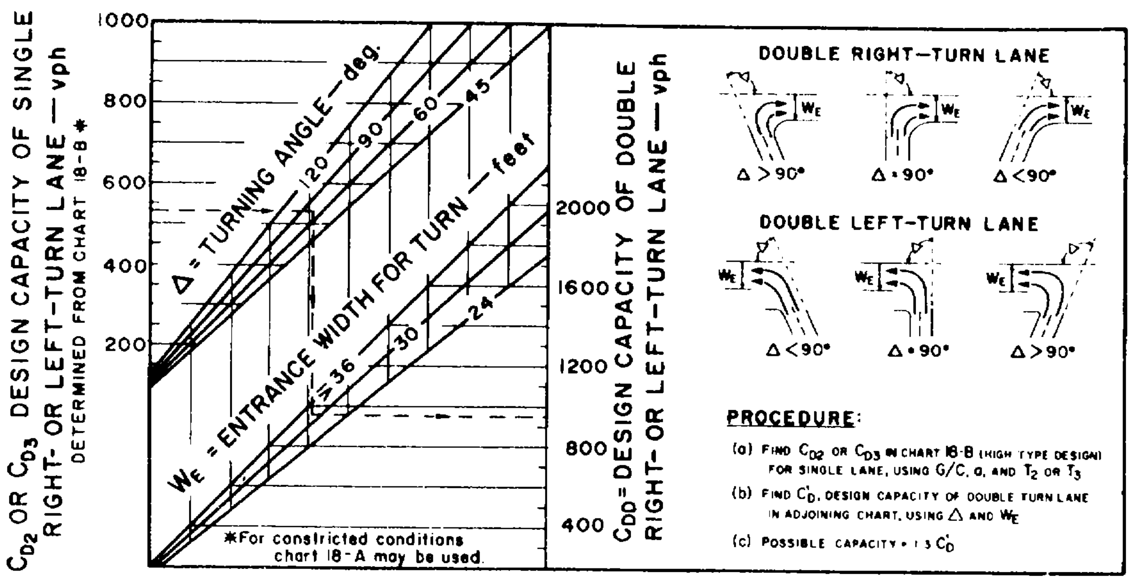
One of the example problems in the 1965 Highway Capacity Manual used a slightly skewed "T" intersection configuration. A dual left-turn lane with a turn angle of less than 90 degrees was shown as part of one of the intersection approaches. The solution of the problem indicated that the dual left-turn lane should be treated similar to a through movement because of the heavy turn volume. There was some latitude, therefore, in selecting the procedure that would be used in a specific case.

At that time, the maximum service volume for capacity conditions was considered to be 1,200 vphg. This would explain why later studies which made comparisons concluded that the procedures in the Manual under-predicted the actual capacity of dual left-turn lanes.

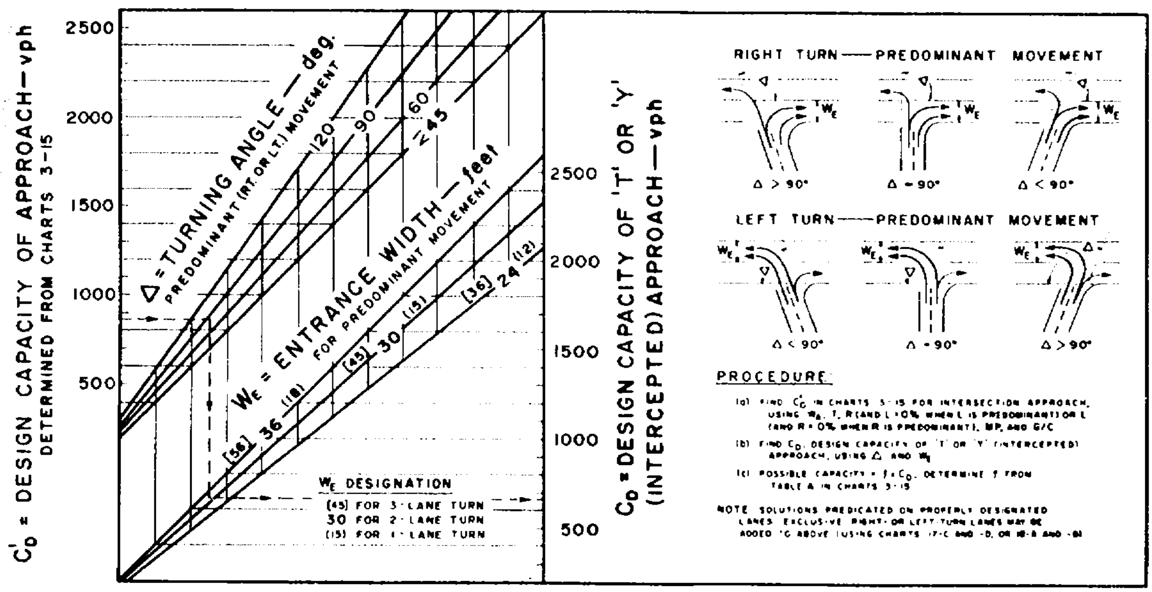
Based on the procedures for signalized intersection capacity as presented in the 1965 Highway Capacity Manual, Leisch developed a set of nomographs and charts which permitted a graphic solution for intersection capacity. This material was subsequently published in Public Roads[13]. The work of Leisch is of particular note in that the capacity of dual turn lanes was related to the angle of turn, the width of the roadway into which the vehicles turned, and the type of intersection. The nomographs and charts for the dual turn lanes conditions are in Figure 3.

During the 1970's, there was an increase in use of "critical movement analysis" for analyzing signalized intersection capacity. In 1980, interim materials on highway capacity[9] were released by the Transportation Research Board and included a procedure for analyzing signalized intersection capacity based on critical movement analysis. As part of the procedure, it was necessary to evaluate a "lane utilization factor". Basically, the lane utilization factor reflected the fact that traffic volumes would not be evenly distributed over the available traffic lanes if more than one lane was provided for the movement. In the case of the dual left-turn lane condition, the procedure suggested that 55 percent of the left-turn volume would be assigned to one of the two lanes. This would imply that the capacity of a dual left-turn lane would be approximately 1.91 times the capacity of a single left-turn lane.

The subsequent work in the development of a new capacity manual took a different direction in terms of the methodology for signalized intersection capacity. The Transportation Research Board Committee on Highway Capacity and Quality of Service decided that the measure of level of service for signalized intersections should be based on delay. As a result, a procedure that evolved was based on saturation flow



a) Capacity of Double Left-Turn Lane



b) Capacity of a "T" or "Y" Intersection

FIGURE 3

DESIGN CHARTS BY LEISCH[12]

concepts. In that procedure, the saturation flow for a "lane" or "lane group" is determined using a base saturation flow value and then adjusting that value for the appropriate intersection conditions. In the early development of the procedure, a base saturation flow rate of 1800 vphg/lane was recommended along with an adjustment factor of 0.80 for dual left-turn lanes[11]. This factor was based on exclusive turn lanes and a protected signal phasing.

The later work on the development of a new manual had the benefit of the more recent research of Stokes[18]; thus the adjustment factor for dual left-turn lanes was modified accordingly in the new Highway Capacity Manual[8]. In the current edition, saturation flow concepts are used as the basis for assessing or determining the capacity of signalized intersections. The recommended adjustment factor for dual left-turn lanes is 0.92. This means that the use of a dual left-turn lane would result in an expected capacity of 184 percent of the single lane condition. Again, the only guidelines that are given are for exclusive dual left-turn lanes with protected signal phasing and for the operational analysis procedure.

Based on the new edition of the Manual, Leisch[13] once more developed nomographs and charts for use in determining the capacity of signalized intersections. The material developed by Leisch again addressed conditions that were not included in the 1985 Highway Capacity Manual[8]. For example, a chart is provided for analyzing dual turn movements at "T" or "Y" junctions. In this case, Leisch suggests that the dual left-turn movement be treated as a through movement and adjustments are made for the angle of turn and the entrance width of the street or roadway into which the turn is being made.

For intersections with four approach legs, exclusive dual left-turn lanes, and protected phasing, Leisch recommends that the capacity of a single left-turn lane be determined. The capacity of the dual left-turn lanes is calculated by applying an adjustment factor to a value that is twice the capacity of the single lane. The following adjustment factors are given:

Angle of Turn (degrees)	Entrance Width (feet)		
	36	30	24
60	0.95	0.85	0.75
90	0.87	0.80	0.70
120	0.80	0.75	0.65

In discussions with Jack Leisch, it was noted that the procedures and factors reflect a rational method and the findings from spot observations. A comparison of the factors for the 90 degree turn condition reveals that the recommended values are less than that shown in the 1985 Highway Capacity Manual[8].

Concurrent with the development of a new manual in the United States, a group in Canada developed and published a capacity guide[21] for signalized intersections. This guide included data from Canadian cities and addressed conditions found in that country. Saturation flow concepts were used as the basis for analyzing and determining the capacity of signalized intersections.

The Canadian work indicates that there is considerable variation in the saturation flow values even for the through movements. Saturation flows were reported to vary with the season, the city, intersection design characteristics, and intersection environment. Typical reported saturation flow values ranged from 1840 to 1350 passenger car units per hour of green time for the through movements.

With respect to double left-turn situations, the following statement is included in the Guide:

> "The saturation flow in the second lane of a double left-turn is affected by how often this practice is used in the area.
>
> In those regions where extensive use of the double left-turns has a longer tradition , saturation flows tend to be equal for both lanes. In regions where double left-turns are not common, the right lane consistently features a substantially lower saturation flow value."

The Canadian publication does address a condition where the outside lane of dual left-turn lanes is shared with a through movement. In that case, the capacity is determined by utilizing the procedures for an exclusive left-turn lane with the procedures for a single shared lane. This discussion of the treatment of shared lane conditions is unique and not found in other publications.

CURRENT RESEARCH

A review of current research was undertaken for the purpose of determining any ongoing efforts that would apply to dual left-turn capacity. In addition to reviewing documents containing status reports on current research, selected individuals who should have knowledge of pertinent research in the area were contacted.

The Transportation Training and Research Center at the Polytechnic University (formerly the Polytechnic Institute of New York) is currently conducting a related project for the Federal Highway Administration. The research project, which was only recently initiated, is focusing on capacity questions that are associated with shared/permissive left-turn lanes. Because the project is limited to shared/permissive left-turn lanes, it is unlikely that the project will include dual left-turn lanes due to the lack of appropriate intersection approaches.

The review did not reveal any other pertinent research that was being conducted at the present time. Certainly, it may be possible that a project or projects may be underway without the normal research community being aware of such efforts; however the approach taken should have identified any major efforts that were either ongoing or planned.

SUMMARY AND CONCLUSIONS

The review of literature revealed a number of publications that contained material related to dual, or double, left-turn lanes. Even with the available literature, the knowledge and understanding of dual left-turn lane capacity and operations is relatively limited. The research studies that have been conducted have yielded results with considerable unexplained variability. In addition, the studies have been somewhat limited with respect to total understanding of dual-left turn lanes in that some pertinent questions have not been addressed.

There is some variation in the application and use of dual left-turn lanes both in terms of design as well as traffic control. Generally, the applications involve exclusive turn lanes and protected signal phases even though other operational configurations and traffic control may be found in Arizona and throughout the United States as well as other countries.

The rationale for using dual left-turn lanes is generally associated with capacity, left-turn storage, and intersection operation. The "rule-of-thumb" guideline that appears throughout the literature suggests the consideration of dual left-turn lanes if the left-turn volume exceeds 300 vehicles per hour.

Most of the research studies have dealt with questions of capacity. A comparison of the findings of the various studies reveals considerable variation in the results. At the current time, the interest in capacity is associated with saturation flow rates and the causes of variation in saturation flow. For this reason, the recent research in Texas[19,20,21] is particularly pertinent because it can be directly related to current signalized intersection capacity procedures. In that work, it was found that saturation flow rates for dual left-turn lanes were much higher than originally thought. At sites in the larger city, the saturation flows approached values that would be expected for through movements. While the findings of that work indicated consistency of the flows for sites in a given city, there was variation in the results with the various cities.

As has been indicated, the research studies have primarily focused on exclusive dual left-turn lanes with protected signal phases. The capacity procedures are generally limited to these conditions.

In terms of safety, the survey by the ITE Committee[22] did attempt to determine the accident experience associated with the use of dual left-turn lanes. Based on the responses from the survey, the results were mixed and inconclusive. A study that specifically documented the accident experience with dual left-turn lanes was not found.

No evidence of ongoing or other proposed dual left-turn research was found. It is unlikely that the current left-turn project sponsored by the Federal Highway Administration will address dual left-turn conditions.

CURRENT RECOMMENDED PRACTICES

Based on the review that was undertaken, the current practice can be summarized as follows:

1. In terms of guidelines for use of dual left-turn lanes, the literature suggests that a left-turn volume of 300 vehicles per hour or more merits consideration of the dual turn lanes. The decision to use the dual turn lanes should be evaluated based on the conditions at a specific intersection site. Intersection and turn lane capacity as well as turn lane storage are important considerations.

2. The 1985 Highway Capacity Manual[8] documents the current practice for the capacity analysis of standard intersections with exclusive dual left-turn lanes and protected signal phases. In essence, the factors in the Manual suggest that a dual left-turn lane has the capacity of 184 percent of the single lane configuration.

3. The work by Leisch[13] provides guidelines for the analysis of dual left-turn lanes at "T" and "Y" intersections. In addition, this reference is useful when considering the angle of turn and the entrance width of the street.

4. Very little information is available about dual left-turn lanes with shared lane configurations or permitted turn conditions. The Canadian Guide[21] does provide some discussion of the capacity analysis of these situations.

Certainly, the current state-of-the-art relative to dual left-turn lanes is not absolute. While the available information does provide valuable insights into the operation and analysis of dual left-turn lanes, the current guidelines and procedures should be used judiciously.

RECOMMENDED RESEARCH

The review of research and publications to date indicates that the capacity of dual left-turn lanes is subject to variation depending on the geographic location and the driving environment of the intersection. The past work suggests that the variation occurs with the basic saturation flow rates. When the current edition[8] of the Highway Capacity Manual was developed, it was recognized that the specific values might be subject to local variation. For this reason, jurisdictions have been encouraged to validate the values in the Manual or develop factors that reflect local conditions and experience.

In spite of the previous research efforts, there are numerous questions that remain unanswered even in terms of dual left-turn capacity. For example, the current procedures for determining dual left-turn capacity are generally restricted to exclusive turn lanes and protected signal phasing. Information about other conditions is rather limited or nonexistent. Also, the review of past work revealed that questions related to the safety of dual left-turn lanes really have not been addressed.

With an increase in use of dual left-turn lanes in Arizona, the results of further research in this area should benefit city, county, and State organizations. The research should document the experience with dual left-turn lanes in Arizona and provide local information for use in operational and design analyses. A detailed description of the proposed project is in the Appendix of this report.

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A P P E N D I X

PROPOSED RESEARCH

PROBLEM TITLE: Capacity of Dual Left-Turn Lanes

PROBLEM STATEMENT:

The <u>1985 Highway Capacity Manual</u> provides limited guidelines and information relative to the assessment of the capacity of dual left-turn lanes. Research has shown there can be considerable variation in the capacity of these lanes depending on the geographic location. With an increase in use of dual left-turn lanes in Arizona, there is a need to develop factors for the assessment of the turn lanes based on local conditions.

RESEARCH OBJECTIVES:

The general objective of the research is to document the experience with dual left-turn lanes in Arizona and develop factors or values to be used in the analysis of intersection design and operations. The research shall also document the safety and accident experience at intersections with dual left-turn lanes.

The following tasks are to be performed:

1) Develop an inventory of dual left-turn lane installations in Arizona. The inventory will include information such as location, physical characteristics of the intersection, type of traffic control, and operation of the left-turn lanes relative to traffic signal phases.

2) Given the inventory of dual left-turn installations, develop a data collection plan that will reflect the range of conditions found in Arizona and the geographic locations of the intersections.

3) Collect field data as necessary at the selected sites. It is suggested that video or time-lapse photographic equipment be used to record the data. The field data collection should include, but not necessarily be limited to, the following information:

- saturation flow data
- angle of dual left-turns
- radius of turn lanes
- street or roadway entry width
- traffic stream composition
- data on traffic in adjacent through lanes

4) Analyze data and develop factors to be used in the analysis of the capacity of dual left-turn lanes. The factors should be compatible with the procedures found in the 1985 Highway Capacity Manual. In essence, the analysis should determine saturation flow rates and variables that affect saturation flow values.

5) Obtain available traffic accident data for the intersections with dual left-turn lanes. If available, "before and after" accident data should be obtained for a specific site.

6) Analyze the available traffic accident data and establish the accident experience with dual left-turn lanes.

7) Recommend values to be used in the capacity analysis of dual left-turn lanes in Arizona. If conditions are found that are not covered in the 1985 Highway Capacity Manual, suggest appropriate procedures and values to be used as permitted by the data from the study.

8) Recommend further research as necessary based on the findings of the study.

9) Prepare a report that documents all work and findings of the project.

EXPECTED IMPLEMENTATION:

The results of the research should provide guidance in the analysis and assessment of dual left-turn lanes to all levels of jurisdictions. The information will be useful in considering the design and operational improvements at intersections.

ESTIMATED FUNDING LEVEL: $120,000

ESTIMATED STUDY DURATION: 18 months